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Adaptation of ecoinvent database to Polish conditions

The case of wood production in the forest

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Abstract
Background, aims and scope This paper is based on the results of a project sponsored by the Ministry of Science and Higher Education and carried out by the Wood Technology Institute in Poznan, Poland. The main purpose of the project was to assess the environmental impact generated during the entire life cycles of chosen wood products. Most of the data came from the Polish wood industry, but some of it was taken from the ecoinvent database, particularly data relating to forest processes. The data were not used as presented in the database but were properly adapted. The aim of the paper is to show how the ecoinvent's initial assumptions have been changed and how the data were adapted. The influence of the adaptation on the characterization results is presented as well.
Materials and methods The adaptation was performed in several steps: obtaining information about the principal assumptions of the ecoinvent database, gathering data appropriate to Polish conditions, changing the principal assumptions to include the Polish situation, calculating the new allocation and correction factors, forming the new inventory tables for round, industrial, and residual wood (softwood and hardwood), and calculating the characterization results to check the influence of the data adaptation on the life cycle assessment (LCA) final results. The following methods have been used: the economic allocation with the allocation correction to include mass, energy, and carbon dioxide uptake from nature and Ecoindicator99 method to assess the environmental impact.
Results The study shows that differences exist between ecoinvent and Polish data for the wood production. Some of the differences are important and significantly impact the final results. The data differ in relation to many factors, for example: tree species, yield of forest, time from planting trees to final harvesting, length and width of forest roads or total area, and land use. The differences in the initial assumptions and further in the allocation factors result in changes of the inventory points and the characterization results. The relevant differences for round hardwood and residual hardwood are not observed. It is not, however, the case of the industrial hardwood where the visible difference exist. The results for all sorts of softwood are completely different and any similarities cannot be observed.
Discussion At present, the total area of forest land in Poland is 9.0 million ha. This is equivalent to 28.8% of the country's area. This means that the forest processes are important for the country. The study could be a part of a more general discussion about the suitability of data recognized by the database's generators as representative for larger areas (Europe, Asia, the world).
Conclusions The following conclusions could be formulated based on the results of the project: differences between countries always exist, and they can be a source of uncertainty, particularly if unspecific data are used. On the other hand, it is impossible to collect specific data for all inventory items included in the product system which is why LCA databases are needed. The following questions should be asked: how important is the discrepancy? What is its influence on the final results? Is it acceptable? There are

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some activities like electricity production where differences between countries can be crucial for the LCA final results. *Recommendations and perspectives* Two main recommendations could be formulated: the data taken from LCA databases should always be critically analyzed and reviewed to check if they are suitable for our case study, and, if possible, the adaptation to local or national conditions should be made.

In Poland, the interest in LCA continues to grow; however, it is not easy for LCA practitioners to conduct LCAs because of companies' skepticism and their reluctance to provide data. LCA databases are important sources of information. A review of the most popular LCA databases could be a good line of further improvement to make LCA studies more relevant and reliable.

Keywords Co-products · ecoinvent database · Economic allocation · Hardwood · Poland · Softwood · Wooden products

1 Goal and scope

This paper is based on the results of a project that was sponsored by the Polish Ministry of Science and Higher Education and had been carried out by the Wood Technology Institute in Poznan between 2003 and 2006. The main purpose of the analysis was to assess the environmental impacts generated during life cycles of chosen wood products (Strykowski et al. 2006). The scope of the project included all the stages, as presented by Fig. 1: from the cradle (wood production in forest), production of semi-products (sawn timber, plywood, particleboards, fiberboards), production of finished goods (furniture, windows and doors, floors, stairs, etc.), to final disposal (incineration and landfilling).

Most of the data used in the project came from the Polish wood industry, except data relating to wood production in the forest. In that case, the ecoinvent database was used (Frischknecht and Jungbluth 2003; Frischknecht et al. 2005; Heijungs et al. 2005). The data were not used as presented in the database but were partially adapted. The aim of the paper is not to present all the results of the project but only this part related to the adaptation of data taken from the database.

2 Materials and methods

The ecoinvent's data on the wood extraction are a main point of interest in the project. There is a distinction in the ecoinvent database between two sorts of actions made in the forest during logging: natural wood production and human activity (known as forest processes; Werner et al. 2003), as presented in Fig. 2.

In the first case, the growth of natural wood takes place based on photosynthesis (the unit process named "hardwood or softwood, standing, under bark, in forest"). There are a few inputs related to this process and included in the ecoinvent's inventories such as: wood standing, carbon dioxide uptake, embodiment of solar energy, and land use. The assimilation of solar energy is defined here to equal calorific gross value of

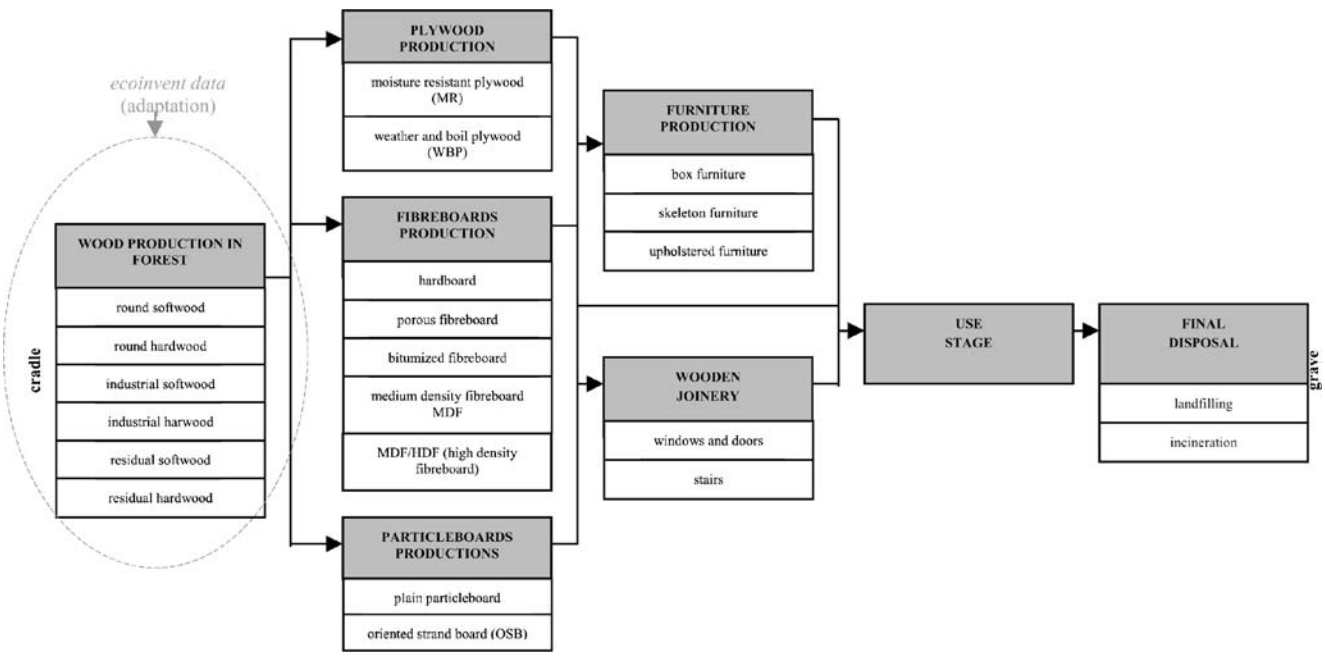

Fig. 1 Data adaptation relating wood production in forest as a part of the whole project

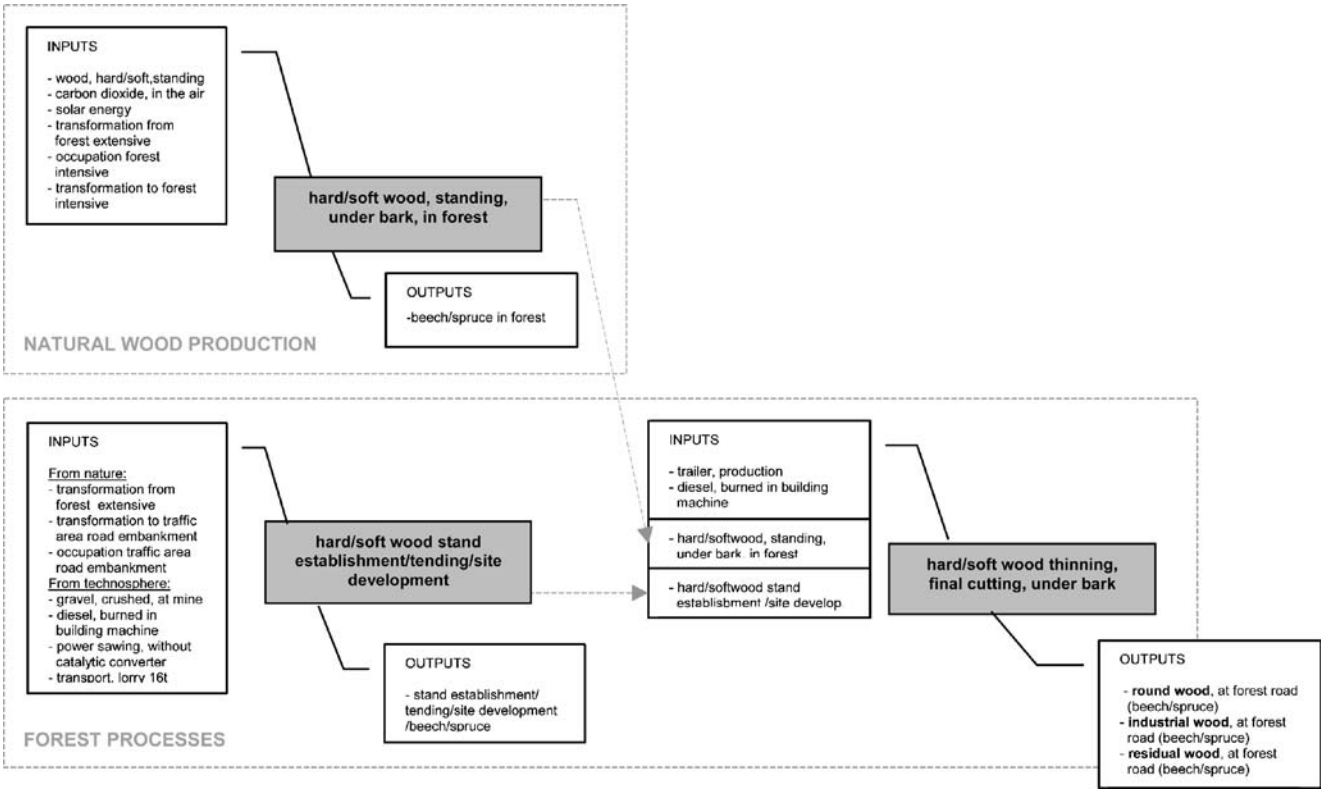

Fig. 2 The main processes in the field of wood extraction in ecoinvent database

wood. The carbon dioxide uptake is calculated based on the carbon content in wood (dry wood matter).

Human activities (or forest processes) encompass several steps, namely: tree nursing, stand establishment, tending, clearing, thinning, cutting, and debarking. There are two main unit processes including all the steps and known as "hardwood or softwood stand establishment, tending, site development" and "hardwood or softwood thinning, final cutting, under bark." Various inputs from nature and the technosphere belong to the unit processes, for example: land use, gravel consumption, fuel (diesel) and power saw use, and transport activity.

Land use is a crucial point in the activity of a forest. Wood extraction causes significant impacts by occupying and transforming the forest area (including forest roads), which leads to a decrease in the ecological quality of the land (in comparison to the primary forest's quality). There is not only a distinction between land occupation and transformation but also between extensive and intensive modes of the use. In the first case, the forest area is used in a more neutral way, for example, by avoiding using fertilizers and limiting the frequency of cutting. The intensive use is more invasive and depends on artificially increasing the forest productivity and more intensive thinning or cutting. Other criterion of the division is a time period when the land is occupied or transformed (default use period). In the ecoinvent database, the interventions are classified according to CORINE land cover classes classification (Bossard et al. 2000; Jungbluth and Frischknecht 2003; Frischknecht 2005).

It is worth mentioning that the adaptation is not performed for all ecoinvent data but only in relation to the selected inventory points. It mainly concerns the natural wood production, but it also includes the selected interventions from the forest processes like land use and gravel consumption. Because of the lack of the appropriate data, some differences between ecoinvent and Polish situations are not explored, for example, relating trailer production, lorry emission factors, and power sawing emissions. The general comparison of the elements for both cases allows for the assumption that the differences exist but are not fundamental.

In order to make the adaptation, the economic allocation and the ecoidicator99 methods are used. Detailed information will be provided in the following sections of the paper.

2.1 Adaptation

The values of the principal parameters concerning wood production may differ depending on the tree species, humidity and density of wood, time from planting trees to final harvesting, and other factors. This means that the initial assumptions can strongly influence the content of inventory tables and further the life cycle impact assess-

ment (LCIA) results. The principal choices made in the ecoinvent database and the level of their convergence with Polish conditions are presented in Table 1 (Strykowski et al. 2006; Werner et al. 2003). As presented in Table 1, only three assumptions made in ecoinvent have been recognized as fully representative for Poland; the others have been changed to make the data more reliable for Polish conditions. The following decisions have been made: softwood is represented by pine, bark mass equals 10% of hardwood's mass and 12% of softwood's mass, density for round softwood is assumed to be 490 kg/m^3 (dry matter) and for round hardwood 690 kg/m^3 (dry matter; Jungbluth and Frischknecht 2003). Other changes are presented in Tables 2 and 3 where the adaptation in relation to land use is shown. Because of the long time from planting tress to final harvesting, these stages are important elements of the life cycle impact (LCI) and LCIA results. It has been observed that there are significant differences in land use data relating to the ecoinvent and Polish situation (see Table 1). The differences are especially visible in the case of land occupation. In both cases, the differences are the main source of discrepancy in the final characterization results. It is worth noting that the numbers presented in Tables 2 and 3 relate to round wood. The highest difference appears in the results concerning softwood. Various yield values, the time from planting trees to final harvesting, and the use of forest land resulted in visibly different areas for land occupation. Particularly relevant is a difference in yield values. This may be the result of many factors including differences in methods of the evaluation of trunk mass, trees growth conditions, felling conditions, etc. However, the difference in rainfall rate between Poland and Switzerland seems to be the most important reason. The values of the parameters for hardwood are more similar, although some differences exist as well.

2.2 Allocation

The problem of allocation is especially important for the wood industry (Jungmeier et al. 2002a, b), and various allocation situations (co-product and reuse or recycle) can appear (Werner 2005). In the case of forestry, three co-products are produced: round wood, industrial wood, and residual wood, as presented by Fig. 2 (Werner et al. 2003). In the ecoinvent database, the economic allocation was used to attribute the environmental impacts to these co-products. For this reason and to ensure the convergence between two analyzed cases, the same approach was used in relation to Polish data. The allocation procedure is based on the following three parameters:

- The amount of the particular co-products
- The economic value of the particular co-products
- The revenue

The problem is additionally complicated because of the importance of the mass and energy balance that is crucial for natural wood production and because it is not properly covered by the economic allocation. The allocation factors can be used for these inventory points where the mass and energy balance does not play a key role (e.g., diesel, burned in building machine or power sawing) while in other cases, a special correction must be used additionally. The correction module is used to allocate the proper mass, energy, and CO_2 uptake from nature (Werner et al. 2003). The allocation and correction factors are calculated according to the method presented in Tables 2 and 3.

The correction factors are expressed in the same unit as the amount of wood is expressed in [m^3], and they can have a positive or negative value. This is because the correction depends on correcting (adding or deducting) the final amount of wood by the value of correction factor. Tables 2

Table 1 The convergence between the ecoinvent's assumptions and Polish situation [1, 5]

No	Assumption	Unit	ecoinvent hardwood (beech)	Poland hardwood (beech)	ecoinvent softwood (spruce)	Poland softwood (pine)
1	Yield	m^3/ha	784	800	1,340	650
2	Time from planting trees to final harvesting	Years	150	140	120	110
3	Forest road length	m/ha	54	80	54	80
4	Forest road width	m	2	4	2	4
5	Forest road area	m^2/m^2	0.0108	0.032	0.0108	0.032
6	Yield (calculated based on 1)	m^3/m^2	0.0784	0.08	0.134	0.065
7	Yield (calculated based on 5 and 6)	m^3/m^2	0.0792	0.083	0.135	0.067
8	Land use forest	m^2/m^3	12.6	12.11	7.4	14.91
9	Land use forest roads	m^2/m^3	0.138	0.4	0.0808	0.49
10	Land occupation forest	m^{2}yr/m^3	1,890	1,695.74	888	1,639.83
11	Land occupation forest road	m^{2}yr/m^3	20.7	56	9.7	54.15

Table 2 Allocation procedure

	(1) Amount	(2) Economic value	(3) Revenue	(4) Allocation factors	(5) Correction (per amount)	(6) Correction (per 1 m^3 of wood)
	m^3	PLN/m^3	PLN	–	m^3	m^3
Round wood	0.55	188	103.4	=103.4/140.9=0.734	$= 0.55/(0.1 + 0.35 + 0.55) - 0.734 = -0.18$	–0.33
Industrial wood	0.35	94	32.9	=32.9/140.9=0.233	$= 0.35/(0.1 + 0.35 + 0.55) - 0.233 = 0.12$	0.33
Residual wood	0.10	46	4.6	=4.6/140.9=0.032	$= 0.10/(0.1 + 0.35 + 0.55) - 0.032 = 0.067$	0.67
Total	1.00		140.90			

and 3 also present the differences between two analyzed cases in the amounts of wood and their economic values. There are no differences between softwood and hardwood in the Polish case while in the ecoinvent, the differences are visible and evident. They lead to various values of allocation and correction factors as presented in Table 4.

The data included in Table 4 show that the environmental impact generated during the production of wood in forest is allocated in different ways between particular co-products (sorts of wood) in the ecoinvent and Polish situations. In both cases, the ranking between particular sorts of wood is the same: the round wood has the higher allocation factor and the residual wood has the lowest one. However, the relationship between particular co-products is rather different. In the Polish case, the industrial wood has a visibly higher allocation factor than in the ecoinvent situation. This is because in Poland, more industrial wood is produced at the cost of the remaining two co-products. The differences in allocation factors lead to the various corrections values. The environmental impact is allocated using allocation and correction factors. The higher allocation factor for roundwood in the ecoinvent case is corrected using a higher negative correction factor while in the Polish case, the lower allocation factor is related to the lower negative correction value.

Table 3 Allocation procedure

	ecoinvent (1) Amount	(2) Economic value	Poland (1) Amount	(2) Economic value
	m^3	CHF/m^3	m^3	PLN/m^3
Softwood				
Round wood	0.65	68	0.55	188
Industrial wood	0.235	44 (20 u=0%)	0.35	94
Residual wood	0.115	28	0.10	46
Hardwood				
Round wood	0.51	133	0.55	188
Industrial wood	0.333	44 (29 u=0%)	0.35	94
Residual wood	0.157	32	0.10	46

It is worth mentioning that the allocation factors presented in Table 4 are used in relation to these inventory points which are common for all three co-products. If some dataset exists which is not used in all cases (for example trailer production is not valid for roundwood), a new allocation situation appears, and the new allocation factors must be evaluated.

The obtained allocation and correction factors are used to change and adapt the data included in the ecoinvent's inventory tables. There are two processes that reflect the division into natural wood production processes and human activities: hardwood or softwood standing under bark and hardwood or softwood stand establishment or site development. They are important elements of the inventory tables for the three wood co-products.

As the adaptation is made mainly in relation to the interventions in the field of the natural wood production, all inventory points presented in Table 5 are changed. The change in wood standing value is an effect of changing the assumption on the bark mass. The carbon dioxide uptake is calculated based on the carbon content in wood. The differences in these values result from various wood standing values and wood density. Solar energy uptake is the same because the identical calorific gross value of wood is assumed in the ecoinvent and Polish situations. The differences in forest transformation and occupation result from all the changes of assumptions related to land use and presented in Table 1.

The inventory data presented in Table 6 include human activity (forest processes). As mentioned earlier, the adaptation is made mainly in relation to the inputs from nature. Because of the lack of data, only gravel use is taken into account and adapted while the remaining inputs from technosphere are not changed. The results presented in Tables 5 and 6 are used to obtain the inventory tables for the

Table 4 Allocation and correction factors—before and after adaptation

	ecoinvent			Poland		
	(4) Allocation factors	(5) Correction (per amount)	(6) Correction (per 1 m^3 of wood)	(4) Allocation actors	(5) Correction (per amount)	(6) Correction (per 1 m^3 of wood)
Softwood						
Round wood	0.82	–0.347	–0.68	0.734	–0.18	–0.33
Industrial wood	0.12	0.239	0.718	0.233	0.12	0.33
Residual wood	0.06	0.109	0.694	0.033	0.07	0.67
Hardwood						
Round wood	0.86	–0.231	–0.355	0.734	–0.18	–0.33
Industrial wood	0.09	0.16	0.681	0.233	0.12	0.33
Residual wood	0.05	0.0715	0.622	0.033	0.07	0.67

production of 1 m^3 of different sorts of wood: round, industrial, and residual (soft and hard). The results of the calculations are presented in Table 7. All the changes resulting from the adaptation are entered into the life cycle assessment (LCA) software in order to perform the impact assessment.

3 Results

The Ecoindicator99 method is used to check the influence of data changes on the final LCA results. The possibility of obtaining the final result as a single number is the reason for using this method. The choice of the LCIA method is rather arbitrary and does not play a key role in the presented analysis. The main aim is to adapt the inventory data, not to analyze the appropriateness of the impact modeling approach to Polish conditions.

The life cycle impact assessment is carried out in relation to the co-products (based on data presented in Table 7). The differences in the environmental burdens for 1 m^3 of particular sorts of wood are calculated. The results are presented in Tables 8 and 9. The main discrepancy lies in two impact categories: climate change and land use, while the numbers for the remaining categories are the same. This results from the changes in such inventory items as carbon dioxide uptake and land use (see Tables 5 and 6). Because most of the inputs from technosphere are the same in the ecoinvent and Polish cases, there are no differences in other impact categories. No relevant differences for round hardwood and residual hardwood are observed. This is not, however, the case with industrial hardwood, where visible differences exist. The results for all sorts of softwood are completely different, and no similarities can be observed (Tables 8, 9).

The following reasons probably contributed to obtaining such results:

- In the ecoinvent, different amounts of outputs (co-products) are attributed to softwood and hardwood, while in the Polish situation, there is no difference between softwood and hardwood.
- The economic values of the particular co-products are different in the ecoinvent and Polish situations. The problem does not lie in different value of money (different currency) but rather in the relationship between the economic values of co-products. In Poland, industrial wood has much higher price in

Table 5 Differences, as a result of data adaptation, in the inventory items for hardwood or softwood standing under bark

Hardwood or softwood standing under bark (per 1 m^3)		Hardwood		Softwood	
		ecoinvent	Poland	ecoinvent	Poland
Inputs from nature					
Wood, hard or soft, standing	M^3	1.12	1.10	1.10	1.12
Carbon dioxide, in the air	Kg	1,320.0	1,399.8	897.0	976.3
Solar energy	MJ	14,300.0	14,300.0	10,100.0	10,100.0
Transformation from forest extensive	M^2	14.11	13.55	8.288	16.69
Occupation forest intensive normal	M^2year	2,120.0	1,897.28	994.56	1,835.68
Transformation to forest intensive normal	M^2	14.11	13.55	8.288	16.69

Table 6 Differences, as a result of data adaptation, in the inventory items for hardwood or softwood stand establishment or tending or site development

Hardwood or softwood stand establishment or site development (per 1 m^3)		Hardwood		Softwood	
		ecoinvent	Poland	ecoinvent	Poland
Inputs from nature					
Transformation from forest extensive	m^2	0.14	0.4	0.08	0.49
Transformation to traffic area road enbankment	m^2	20.7	56.0	9.7	53.9
Occupation traffic area road enbankment	m^2year	0.14	0.4	0.08	0.49
Inputs from technosphere					
Gravel, crushed, at mine	kg	132.0	0.0	62.1	0.0
Diesel, burned in building machine	MJ	5.75	5.75	2.06	2.06
Power sawing, without catalytic converter	h	0.053	0.053	0.02	0.02
Transport, lorry 16 t	tkm	6.62	6.62	3.1	3.1

relation to the other two sorts of wood than is assumed in the ecoinvent. Additionally, a relevant difference in the economic value is observed for round softwood (in Poland, the value is much higher than in the ecoinvent database).

– There are relevant differences in the allocation and correction factors which cause discrepancies in the inventory items.
– Assumptions and data regarding land use differ significantly. It is important in both cases, especially in the case of softwood. The higher values for yield and forest road area lead to higher ecoindicator results for data concerning Poland.
– Higher values of wood density resulted in higher carbon content in dry matter, which leads to higher carbon dioxide uptakes and higher environmental benefit (characterization result for climate change). The profit exists when analyzing the result from the cradle point of view. If one takes into account the whole life cycle, the potential benefit can be nullified by the releases during final disposal (e.g., incineration). The data adaptation is performed only in relation to the cradle (see Fig. 1), so it goes beyond the scope of this paper to present the results for the whole life cycle.

4 Conclusions

The analysis shows that differences between the ecoinvent and Polish situations exist, especially in the case of softwood. This results from the differences in the initial assumptions. The LCIA results for round and residual hardwood are rather similar because the differences in allocation factors are compensated by the differences in correction values. For example, round hardwood has a higher allocation factor in the ecoinvent case, so higher environmental impact should be allocated to this element. At the same time, it has higher negative correction value, so a higher amount of wood (and impact) is subtracted from the final result. For this reason, the discrepancy is rather minimal. The allocation and correction factors are different for industrial wood, so the LCIA results are varied both for softwood and hardwood.

Table 7 Inventory tables adapted to Polish conditions for production of 1 m3 round, industrial and residual wood

Inputs from technosphere (per 1 m^3 of wood)		Round hardwood	Industrial hardwood	Residual hardwood	Round softwood	Industrial softwood	Residual softwood
Trailer, production	kg	–	1.05	0.51	–	1.05	0.51
Diesel, burned in building machine	MJ	60.58	30.29	14.82	103.01	51.5	25.2
Power sawing, without catalytic converter	h	0.2	0.1	0.05	0.33	0.17	0.08
Hardwood or softwood, allocation correction (1,2,3)	M^3	–0.33	0.33	0.67	-0.33	0.33	0.67
Hard/softwood, stand establishment/tending/site development, under bark	m^3	1.63	0.815	0.399	1.63	0.815	0.399
Hard/softwood, standing, under bark, in forest	M^3	1.63	0.815	0.399	1.63	0.815	0.399

Table 8 The LCIA results (ecoindicator99) for different sorts of hardwood, before and after adaptation

Impact category	Unit	Round wood, hardwood, under bark, u=70%, at forest road		Industrial wood, hardwood, under bark, u=80%, at forest road		Residual wood, hardwood, under bark, u=80%, at forest road	
		ecoinvent	Poland	ecoinvent	Poland	ecoinvent	Poland
Carcinogens	Pt	0.0372	0.0372	0.0705	0.0705	0.0738	0.0738
Resp. organics		0.00764	0.00764	0.00192	0.00192	0.00204	0.00204
Resp. inorganics		1.48	1.48	0.442	0.442	0.468	0.468
Climate change		–7.14	–7.58	–7.18	–7.62	–7.18	–7.62
Radiation		0.00107	0.00107	0.00106	0.00106	0.00111	0.00111
Ozone layer		4.90E-05	4.90E-05	1.78E-05	1.78E-05	1.88E-05	1.88E-05
Ecotoxicity		0.03	0.03	0.0243	0.0243	0.0254	0.0254
Acidification/eutrophication		0.154	0.154	0.0387	0.0387	0.041	0.041
Land use		31.9	33	7.15	16.3	7.58	8.04
Minerals		0.00738	0.00738	0.032	0.032	0.0334	0.0334
Fossil fuels		0.664	0.664	0.242	0.242	0.256	0.256
Ecoindicator		27.1	27.8	0.818	9.52	1.3	1.32

The uncertainty included in the adaptation's results originates mainly from two elements: the lack of Polish data for most inputs from technosphere and the uncertainty included in the chosen LCIA method. The second problem could be solved by using a sensitivity analysis and making a comparison between the impact assessment results obtained by using different LCIA methods. The first issue is more problematic, and only further efforts to gather appropriate data could be reasonably hoped for. It is probable that the changes in the inventory points related to the technosphere would lead to changes in the indicators for the remaining impact categories.

For adaptation purposes, it is crucial to make available the methodological reports where the principal assumptions and calculations made by database generator are presented. The adaptation presented in the study would not be possible if the ecoinvent's reports were not published.

In Poland, the interest in LCA continues to increase; however, it is not easy for LCA practitioners to conduct LCAs because of companies' skepticism and their reluctance to provide data. LCA databases are important sources of information. A review of the most popular LCA databases could be a good approach for further improvement in making LCA studies more relevant and reliable.

Table 9 The LCIA results (ecoindicator99) for different sorts of hardwood, before and after adaptation

Impact category	Unit	Round wood, softwood, under bark, u=70%, at forest road		Industrial wood, softwood, under bark, u=140%, at forest road		Residual wood, softwood, under bark, u=140%, at forest road	
		ecoinvent	Poland	ecoinvent	Poland	ecoinvent	Poland
Carcinogens	Pt	0.0287	0.0287	0.0925	0.0925	0.106	0.106
Resp. organics		0.00838	0.00838	0.00272	0.00272	0.00308	0.00308
Resp. inorganics		1.71	1.71	0.645	0.645	0.735	0.735
Climate change		–4.83	–5.26	–4.87	–5.29	–4.85	–5.29
Radiation		0.000588	0.000588	0.00128	0.00128	0.00146	0.00146
Ozone layer		4.83E-05	4.83E-05	2.32E-05	2.32E-05	2.65E-05	2.65E-05
Ecotoxicity		0.0246	0.0246	0.0309	0.0309	0.0354	0.0354
Acidification/ Eutrophication		0.18	0.18	0.0578	0.0578	0.0657	0.0657
Land use		12.2	31.6	3.53	15.7	4.01	7.74
Minerals		0.00548	0.00548	0.0426	0.0426	0.049	0.049
Fossil fuels		0.659	0.659	0.318	0.318	0.362	0.362
Ecoindicator		9.95	29	–0.148	11.6	0.519	3.81

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